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Mach-Zehnder

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Wavelength Conversion by Optimized Monolithic Integrated Mach-Zehnder Interferometer

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Abstract—Semiconductor optical amplifiers have been monolithically integrated in a passive symmetric Mach-Zehnder interferometer to form a compact polarization insensitive all-optical wavelength converter operating at up to 10 Gb/s. A simple method for reducing the impact of input power variations is proposed that increases the input power dynamic range from 4–8 dB.

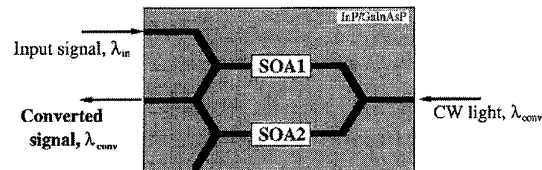


Fig. 1. Wavelength conversion principle. SOA1 acts as a phase shifting element.

I. INTRODUCTION

WAVELENGTH converters will enable construction of simple and flexible WDM networks, since they reduce the number of wavelengths needed and relaxes the requirements to the wavelength precision throughout the network [1]. In addition, wavelength converters can be exploited in space switches as well as for TDM to WDM transmultiplexing [2]. Consequently, the development of effective and practical all-optical wavelength converters has attracted considerable attention. The most promising all-optical wavelength converters rely on optical modulation of gain or refractive index in semiconductor optical amplifiers (SOA's) [3]–[9].

Especially, the optically induced refractive index change (cross-phase modulation) in SOA's integrated in for example a Mach-Zehnder interferometer (MZI) has recently resulted in very effective wavelength conversion [4]–[9]. Desirable features such as effective up and down conversion, high-speed operation as well as low chirping of the converted signals have been obtained simultaneously. Here, we present results for an improved version of the Mach-Zehnder interferometer wavelength converter [7]. The monolithic integrated converter features a separate branch for the input signal and operates at 5 and 10 Gb/s. It exhibits excellent properties such as wavelength independent conversion and high stability. Furthermore, this refined device allows for in-phase conversion (where the converted signal is not inverted compared to the input signal) and conversion without an output optical filter. Finally, we propose and experimentally confirm a simple method for optimizing the conversion performance when variations in the input power alters the optimum operation point of the MZI.

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II. PRINCIPLE AND DEVICE CHARACTERISTICS

The principle of operation for the converter is as follows (see Fig. 1): A CW-signal with the desired output wavelength, λ_{conv} , is coupled to the MZI and split equally to each interferometer arm in a 3 dB Y-junction. After amplification in the SOA's the CW-signal recombines at the output either constructively or destructively depending on the relative phase-difference, $\Delta\phi$, between the two interferometer arms. The SOA's control $\Delta\phi$ depending on the bias currents as well as the optical power injected into SOA1. Therefore, by injecting the intensity modulated input signal (λ_{in}) to SOA1 by a separate waveguide branch [6]–[8] the CW-signal will experience constructive or destructive interference according to the input signal information. All-optical wavelength conversion from λ_{in} to λ_{conv} is obtained.

To accomplish high operation stability as well as small size, the MZI with the SOA's must be integrated. The monolithic integration of the 1200 μm long bulk type SOA's and the interferometer is achieved using the buried strip loaded waveguide structure [10]. The Y-junctions have wavelength and polarization independent power splitting in the wavelength range considered.

III. RESULTS AND DISCUSSIONS

The basic interferometer characteristic is assessed by measuring the static performance as shown in Fig. 2. The output power at 1535 nm (CW wavelength) versus the input power at 1543 nm (signal wavelength) verifies a pronounced interferometric behavior: A change in input power of 10 dB leads to an output power change of 20 dB.

The conversion capabilities of the MZI are assessed by BER measurements. To achieve high conversion speed the bias current to SOA1 is high (300 mA) while the bias current to SOA2 is adjusted to give maximum extinction ratio for the converted signal (see Fig. 2). Examples of measured BER curves at 5 Gb/s for both the input and converted signals are shown in Fig. 3 for conversion from 1543 to 1535 nm

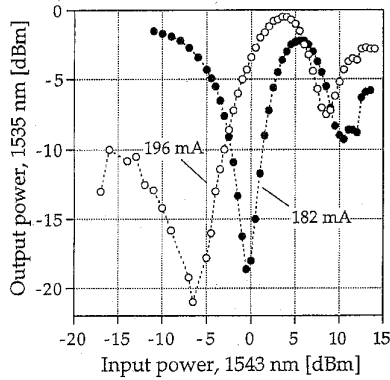


Fig. 2. Static characteristics: Output power at $\lambda_{\text{conv}} = 1535$ nm versus the input power at $\lambda_{\text{in}} = 1543$ nm for two different SOA2 bias currents. All powers are measured in the fiber. Bias current to SOA1 = 300 mA. Input CW power = 6 dBm.

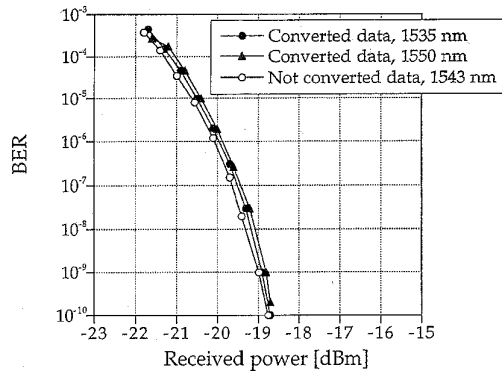


Fig. 3. BER curves at 5 Gb/s for the input signal (1543 nm) and for the converted signals at 1535 and 1550 nm, respectively. PRBS length = $2^{31} - 1$. Input signal power = -2 dBm. Bias current to SOA1/SOA2 = 300 mA/196 mA. Input CW power = 6 dBm.

and 1550 nm, respectively. The signal (extinction ratio ~ 13 dB) and CW signals are coupled co-directional to the MZI so an optical filter (40 GHz) has been applied to select the converted signal at the output. Wavelength conversion with a penalty below 0.5 dB for both up and down conversion is attained at 5 Gb/s independent of the signal polarization. At 10 Gb/s the penalty increases to ~ 2 dB mainly due to a low optical confinement factor (~ 0.3) in the SOA that limits the conversion speed [9].

Similar excellent performance as described above can be obtained within a 30 nm wavelength range [5]–[7]. This is a unique property for the cross-phase modulation technique exploited here in contrast to wavelength converters relying on for instance cross-gain modulation or four-wave-mixing in SOA's. Moreover, it is important to observe that the MZI can conserve the bit-polarity (no inversion of the converted signal), thus enabling excellent transmission performance for the converted data over nondispersion shifted fibers as described in [5]. Note that a similar good performance is obtained for counter directional coupling of the signal and the CW light. Even without the optical filter a penalty below 1 dB is achieved

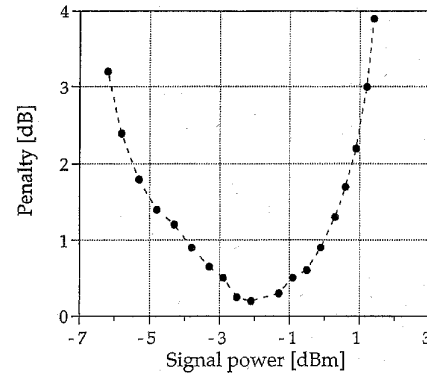


Fig. 4. Penalty (@ BER = 10^{-9}) at 5 Gb/s for conversion from 1543 nm to 1535 nm. Input signal power = -2 dBm. Bias current to SOA1 = 300 mA. Input CW power = 6 dBm. Bias current to SOA2 = 196 mA.

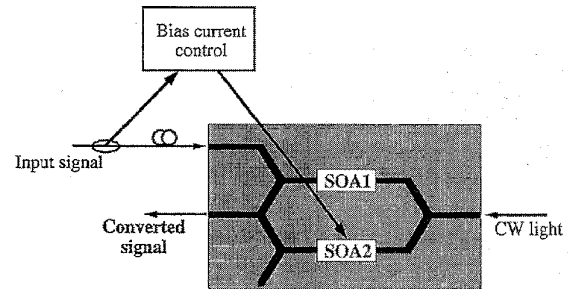


Fig. 5. Control set-up for compensation of variations in input power.

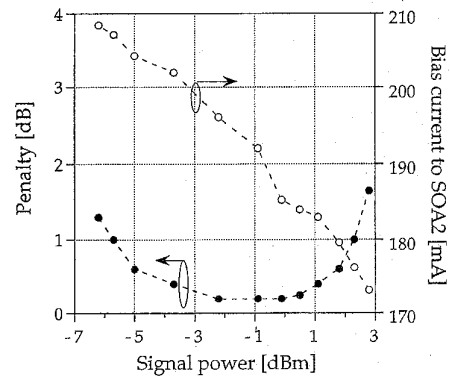


Fig. 6. Penalty (@ BER = 10^{-9}) at 5 Gb/s for conversion from 1543 nm to 1535 nm. Input signal power = -2 dBm. Bias current to SOA1 = 300 mA. Input CW power = 6 dBm. Bias current to SOA2 is adjusted (right axis) to minimize the conversion penalty.

at 5 Gb/s. Consequently, the MZI converter operates without a tunable output filter which eases the implementation in real networks.

Recently, both extinction ratio improvement [4] and low chirping of the output signal [5] has been demonstrated by interferometric wavelength converters. These excellent properties arise due to the operation principle where only ~ 4 dB gain variation is required to change the phase in the SOA by π (necessary to shift from constructive to destructive interference or vice-versa). Therefore, the wavelength conversion is very

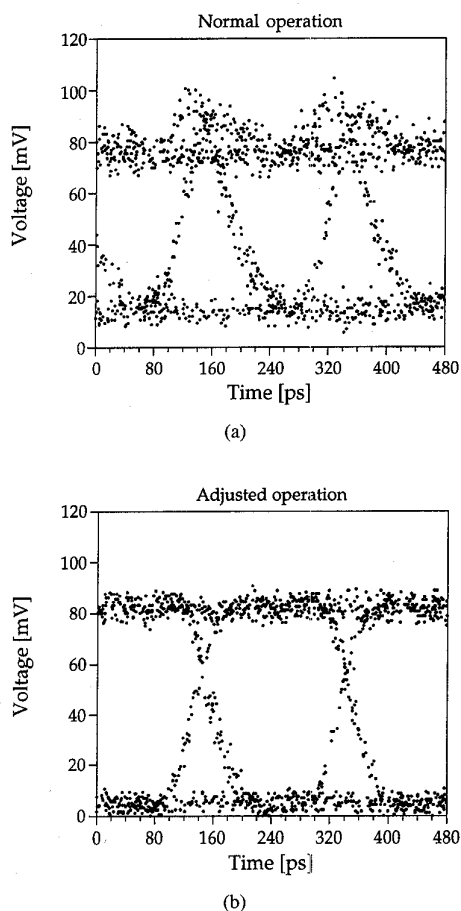


Fig. 7. Eye diagram examples for converted data at 5 Gb/s for a signal input power of 1 dBm for conversion from 1543 nm to 1535 nm. Bias current to SOA1 = 300 mA. Input CW power = 6 dBm. (a) Bias current to SOA2 = 196 mA. (b) Bias current to SOA2 = 182 mA.

power efficient. This can however, also be considered a disadvantage since the converter may become very sensitive to input power variations that could occur in WDM networks where different channels may arrive to the wavelength converter with different power levels. In Fig. 4, the penalty at 5 Gb/s for down conversion is shown versus the signal input power. The 1-dB dynamic range for the input power is about 4 dB. Hence, for larger input power variations the MZI must be externally adjusted.

As indicated in Fig. 2, control of the bias current to SOA2 provides a simple method for optimizing the conversion performance of the MZI when the input power is changed. A control set-up for the MZI could be that shown in Fig. 5: The average input signal power is here measured by a controller which in turn adjusts the bias current to SOA2 according to well known characteristics of the MZI (like the data shown

in Fig. 2). The principle is assessed in Fig. 6, which gives the penalty and optimized bias current to SOA2 versus the signal input power. The dynamic range is now improved to 8 dB by adjusting the current between 170 mA and 210 mA. Examples of eye diagrams for 1 dBm input power are shown in [Fig. 7(a) and (b)] for cases without (196 mA) and with (182 mA) adjustment, respectively.

IV. SUMMARY

A compact and stable polarization insensitive wavelength converter implemented as a monolithic Mach-Zehnder interferometer with semiconductor optical amplifiers has been realized in InP-GaInAsP. The device demonstrates wavelength independent conversion at up to 10 Gb/s. Assessment of the input power dependency without adjustment of the operating conditions reveals a 1-dB dynamic range of approximately 4 dB. A method for adjusting the performance for large power variations is proposed. It increases the dynamic range to 8 dB by adjusting the bias current to one of the SOA's.

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